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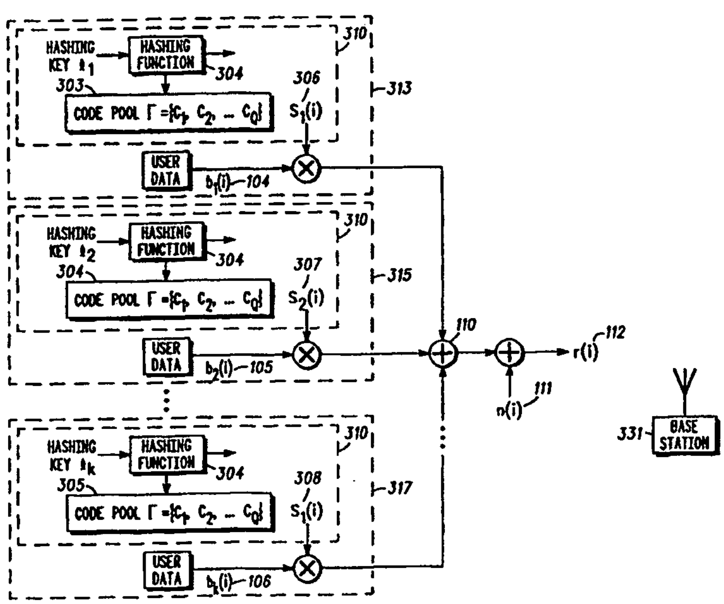

(57) Abstract

The invention describes a method and apparatus for hopping the short spreading code assigned to each user in a Direct–Sequence Spread–Spectrum (DS–SS) Code Division Multiple Access (CDMA) communications system. The sequence of short spreading codes employed by each user is determined by a pseudo–random hashing function (310). The set of short spreading codes (304) available to each user is drawn from one of (possibly) several disjoint sets of short spreading codes made available to a cellular communication system. The

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METHOD AND APPARATUS FOR SHORT SPREADING IN A CODE DIVISION MULTIPLE ACCESS COMMUNICATION SYSTEM

Field of the Invention

The present invention relates generally to communication systems, and more particularly to a method and apparatus for short spreading code hopping in a code division multiple access (CDMA) communication system.

Background of the Invention

During the 1990's cellular communications systems based on Direct Sequence Spread Spectrum (DS-SS) Code Division Multiple Access (CDMA) principles have become increasingly important. In evidence of this, systems adhering to the Telecommunications Industry Association (TIA) IS-95 standard "Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular Standard" and the American National Standard Institute (ANSI) J-STD-008 "Personal Station-Base Station Compatibility Requirements for 1.8 to 2. 0 GHz Code Division Multiple Access (CDMA) Personal Communications Systems" have been commercially deployed worldwide. Interest in the DS-SS CDMA approach to cellular systems design continues to increase, and it is widely anticipated that the International Telecommunication Union (ITU) standard for a global "3rd-Generation" or "3G" personal communication system will be based on DS-SS CDMA principles.

Until recently, commercial receiver designs for both the forward (base station (BS) to mobile station (MS)) and reverse (MS to BS) links in DS-SS CDMA cellular communications systems have been based on variants of the classical RAKE receiver architecture described in "A Communication Technique for Multipath Channels," Price R., Green P. E. Jr., Proc. IRE, vol. 46, pp. 555-570, Mar. 1958. In more recent system designs, the reverse link has been revised to permit – in common with the forward link – pilot symbol transmission for

channel estimation and coherent symbol recovery and combining as outlined in Chapter 11 of *Communications Systems and Techniques*, Schwartz M. Bennett W. R., Stein S, IEEE Press. The fundamental architecture of a single-user rake receiver operating without consideration of other-user interference has, however, remained the *de-facto* receiver standard for deployed CDMA cellular systems.

It is known, however, that the RAKE receiver is not optimal when information is available concerning the interference from other users sharing the same RF channel. This information may be limited only to an awareness of the existence of other users and of the type of spreading codes assigned, or may extend to include precise information on the spreading codes, timing epochs, and multipath channel structure of each interfering user. Examples of receivers exploiting this information (usually sub-optimally, due to the computational complexity of the optimal solution) are known, and have been described in various tutorial articles including "Multi-User Detection for DS-CDMA Communications," Moshavi S., IEEE Communications Magazine, pp. 124-136, Oct. 1996, and "Multiuser Detection for CDMA Systems," Duel-Hallen A., Holtzman J., Zvonar Z, IEEE Personal Comm. Mag., pp. 46-58, Apr. 1995. Such receivers are variously referred to in the literature as interference canceling receivers (ICR's), multi-user detectors (MUD's), or joint detectors (JD's).

MUD's that have been proposed can be divided into those generally considered suitable for systems using long spreading sequences (i.e., where the spreading code period is much longer than the channel encoded symbol interval) and those proposed for systems with short spreading codes or "signature sequences" (i.e., where the spreading code period is equal or comparable in length to the channel symbol interval).

An example of the former type of MUD includes the serial subtractive interference cancellation method described in US Patent 5,235,612, "Method and Apparatus for Cancelling Spread Spectrum Noise," and in "Analysis of a Simple Successive Interference Cancellation Scheme in a DS/CDMA System," Patel P., Holtzman J., IEEE J. Sel. Areas Comm., Vol. 12, No. 5, June 1994. A further example is the parallel subtractive interference approach described in "Multistage Detection in Asynchronous Code-Division Multiple-Access Communications,"

Varanasi M. K., Aazhang B., IEEE Trans. Comm., vol. 38, no. 4, Apr. 1990, and US Patent 5,363,403 "Spread Spectrum CDMA Subtractive Interference Canceler and Method."

These approaches are often preferred for long code applications because it is generally believed that alternative symbol or sequence-oriented methods, such as the decorrelating MUD (or zero-forcing MUD) and the minimum mean-square error (MMSE) MUD (see, for example, "Linear Multiuser Detectors for Synchronous Code-Division Multiple-Access Channels," Lupas R., Verdu S., IEEE Trans. Inf. Theory, vol. 32, pp. 123-136, Jan. 1989) are excessively complex – especially for large numbers of users – since the associated linear inverse operators must be revised at the symbol rate. Such approaches are generally considered better suited, however, for short code systems since the correlation coefficients between user short codes pairs are time invariant in Additive White Gaussian Noise (AWGN) channels, or – in the case of fading channels – are approximately constant over the channel coherence interval.

The use of short codes can also simplify the implementation of the parallel and serial successive interference cancellation methods, since – provided some means of channel estimation is available – the resulting knowledge of the user code cross-correlation matrix avoids the need to re-spread intermediate symbol decisions between stages. Further, short codes enable adaptive MUD's which exploit the cyclostationarity of the other-user interference to suppress interfering signal vectors, as described, for example, in US Patent 5,343,496 "Interference Suppression in CDMA Systems." This latter approach also offers a direct means of suppressing other-cell interference without the need for the cellular system network to pass information on active spreading codes between base stations.

Accordingly, the provision of optional short code spreading modes is being considered for application in 3G CDMA systems by the international standards processes described above. For example, two of the candidates – the Wideband CDMA (W-CDMA) and Time Division CDMA (TD-CDMA) proposals – considered by the European Telecommunications Standards Institute (ETSI) for the emerging Universal Mobile Telecommunications System (UMTS) standard incorporate a short spreading code mode (the W-CDMA approach, for

example, is described in Appendix A of ETSI Document 30.06, "UMTS Terrestrial Radio Access (UTRA) Concept Evaluation".

There are at least three drawbacks associated with the use of short codes, however. First, the inter-user interference averaging offered by the randomization of user code correlation coefficients is lost. This requires some care in the design and allocation of the short code set if conventional single user detectors are to be used. Second, the power spectrum of signals spread using short codes may contain significant and undesirable structure depending on the design of the short code family. Third – and most importantly for the present purpose – the bit error rate for users spread by particular codes may be worse than others, even if an MUD receiver is used and the same energy per information bit E_b is offered to the receiver by each user.

This can be illustrated by the following analysis. Consider the simple discrete-time multi-user communications system model of FIG. 1. The figure shows K homogeneous and synchronous users 101-103 (i.e., all users 101-103 are transmitting at the same symbol rate, and the symbol boundary of each user is aligned at the receiver) simultaneously transmitting binary phase shift keyed (BPSK) symbol sequences via an AWGN channel to a single receiver antenna port. Note that the assumptions that the users are homogeneous and synchronous are used solely to simplify the following discussion – extension to the asynchronous, inhomogeneous case is straightforward.

In FIG. 1 the i-th BPSK symbol transmitted to base station 131 by user k is $b_k(i)$ 104-106 and the (generally complex-valued) length-N short code assigned to the user k is $\mathbf{s}_k$ 107-109 where

$$\mathbf{s}_k = [s_k(1), s_k(2), \ldots, s_k(N)]^T.$$

The energy transmitted per information bit by user k is equal to $E_{b,k}$ where $\mathbf{s}_k$ is assumed to have unit norm. $E_{b,k}$ is identical for each user, i.e., $E_{k,b} = E_b$.

Continuing, the spread waveform associated with each user symbol is summed by the channel 110 and combined 113 at the receiver with a complex-valued, zero-mean, uncorrelated Gaussian noise vector $\mathbf{n}(i)$ 111 of variance N_t to form the length-N signal vector $\mathbf{r}(i)$ 112 observed by the receiver during the i-th symbol interval.

By concatenating the user BPSK symbols transmitted in the i-th interval it is possible to form the transmitted symbol vector $\mathbf{b}(i)$ as

$$\mathbf{b}(i) = [b_1(i), b_2(i), \ldots, b_K(i)]^T.$$

By additionally forming the NxK spreading code matrix $\mathbf{S}$ as

$$\mathbf{S} = [\mathbf{s}_1, \mathbf{s}_2, \ldots, \mathbf{s}_K]$$

the receiver observation $\mathbf{r}(i)$ formed during the i-th symbol interval may be expressed as

$$\mathbf{r}(i) = \sqrt{E_b}\mathbf{S}(i)\mathbf{b}(i) + \mathbf{n}(i).$$

With this background, the type of linear, memoryless, multi-user detector generally referred to in the literature as the "decorrelating" or "zero-forcing" MUD may be defined and then used to describe how the bit error rate for each user differs.

The decorrelating detector may be viewed as the least-squares estimate $\hat{\mathbf{b}}(i)$ of the transmitted symbol vector $\mathbf{b}(i)$ according to

$$\hat{\mathbf{b}}(i) = \mathbf{L}\mathbf{r}(i)$$

where the linear operator $\mathbf{L}$ is the standard least-squares solution operator

$$\mathbf{L} = [\mathbf{S}^H\mathbf{S}]^{-1}\mathbf{S}^H\mathbf{r}(i)$$

One possible implementation a prior-art MUD is shown in FIG. 2. Here, K code matched filters 201-203 output the vector $\mathbf{S}^H \mathbf{r}(i)$ (decimated 204-206 by N from the chip rate to the symbol rate) to a digital signal processor (DSP) 207 which multiplies the resulting vector by the matrix $[\mathbf{S}^H\mathbf{S}]^{-1}$ formed *a-priori* by the DSP from knowledge of the assigned short code sequences to generate the symbol estimate vector $\hat{\mathbf{b}}(i)$ 208-210. Rather than directly inverting $\mathbf{S}^H\mathbf{S}$ many other approaches to solving the least-squares kernel are also feasible, including for example, gradient optimization methods such as the conjugate gradient method, projection methods, or matrix decomposition methods.

Analysis of the resulting symbol error rate for each user at the detector output may be performed as follows. The symbol estimate $\hat{\mathbf{b}}$ output by the decorrelating detector may be expressed as

$$\begin{aligned}\hat{\mathbf{b}}(i) = \mathbf{L}\mathbf{r}(i) &= [\mathbf{S}^H\mathbf{S}]^{-1}\mathbf{S}^H[\sqrt{E_b}\mathbf{S}\mathbf{b}(i) + \mathbf{n}(i)] \\ &= \sqrt{E_b}\mathbf{b}(i) + [\mathbf{S}^H\mathbf{S}]^{-1}\mathbf{S}^H\mathbf{n}(i) \\ &= \sqrt{E_b}\mathbf{b}(i) + \mathbf{m}(i)\end{aligned}$$

That is, the decorrelating detector yields an unbiased estimate of the transmitted symbols, subject to a zero-mean, Gaussian error vector $\mathbf{m}$, where the autocovariance matrix $\mathbf{R}_m$ of $\mathbf{m}$ may be expressed as

$$\mathbf{R}_m(i) = [\mathbf{S}^H\mathbf{S}]^{-1}N_t$$

The main diagonal of $\mathbf{R}_m$ specifies the variance of the solution error on each user symbol estimate, and – since the operator $\mathbf{L}$ is linear and the symbol error vector $\mathbf{m}$ is therefore zero-mean and Gaussian – also defines the symbol error rate for each user as a function of the single-user signal-noise ratio E_b / N_t. This follows from the standard coherent BPSK bit error result that given the variance σ_k^2 of the Gaussian noise on the k-th user's symbol estimate as

$$\sigma_k^2 = [\mathbf{S}^H\mathbf{S}]^{-1}{}_{(k,k)} N_t$$

where $[\mathbf{S}^H\mathbf{S}]^{-1}{}_{(k,k)}$ denotes the k-th element of the diagonal of $[\mathbf{S}^H\mathbf{S}]^{-1}$, then the probability of symbol error P_k for the k-th user can be written as

$$P_k = Q(\sqrt{2E_b / \sigma_k^2}).$$

For the present purpose, it is important to realize that the error variance σ_k^2 is generally not the same for each user, and therefore – even if the energy per bit E_b is the same – the symbol error probability P_k will also differ.

This can be readily appreciated by decomposing the matrix $\mathbf{S}^H\mathbf{S}$ using the similarity transform, where – again for simplicity – it is assumed that the columns of $\mathbf{S}$ are linearly independent, and that the number of users K is equal to the sequence length N. $\mathbf{S}^H\mathbf{S}$ can be decomposed as $\mathbf{S}^H\mathbf{S} = \mathbf{V}^H\mathbf{\Delta}\mathbf{V}$ where $\mathbf{V}$ is a unitary matrix whose columns are the eigenvectors of $\mathbf{S}^H\mathbf{S}$, and – since $\mathbf{S}^H\mathbf{S}$ is a normal matrix – $\mathbf{\Delta}$ is a diagonal matrix comprising the K real-valued and non-negative eigenvalues λ_k of $\mathbf{S}^H\mathbf{S}$. Accordingly

$$[\mathbf{S}^H\mathbf{S}]^{-1}{}_{(k,k)} = [\mathbf{V}^H\mathbf{\Delta}^{-1}\mathbf{V}]_{(k,k)}$$

and so – since $\mathbf{V}$ is a unitary matrix and $\mathbf{\Delta}$ is diagonal – the noise variance σ_k^2 of the k-th user is given by

$$\sigma_k^2 = \frac{N_t}{\lambda_k^2}$$

Note, however, that the eigenvalues λ_k of $\mathbf{S}^H\mathbf{S}$ are not generally equal. If this were so, then

$$\mathbf{S}^H\mathbf{S} = \mathbf{V}^H\Delta\mathbf{V} = \lambda\mathbf{V}^H\mathbf{I}\mathbf{V} = \lambda\mathbf{I}\mathbf{V}^H\mathbf{V}$$

but – since $\mathbf{V}$ is unitary – this can only be true if the short code set $\mathbf{s}_k$ forms an orthogonal set.

Thus, even if the energy per bit E_b is the same for each user, the probability of symbol error is not the same at the decorrelating MUD output. In general, the extent of the difference in BER associated with each code will depend on the eigenvalue spread for the matrix $\mathbf{S}^H\mathbf{S}$, i.e., it will depend on the condition number κ of the matrix $\mathbf{S}^H\mathbf{S}$ where κ is defined as the ratio $\lambda_{\max} / \lambda_{\min}$ of the maximum and minimum eigenvalues.

Finally, although the background of the invention has been presented in the context of the decorrelating detector, the result can be generalized using likelihood analysis to show that other MUD's will generally experience the same dependency of BER with user code.

It is theoretically possible to normalize the BER performance of all the users by using an appropriate short code set. For example, the use of an orthogonal short code set – as shown above – renders the BER of all the users the same. It is not generally possible, however, to design a short code set which maintains orthogonality for an asynchronous user population under multipath fading channel conditions.

Accordingly, a need exists for a method and apparatus for short code spreading in a CDMA communication system that normalizes user bit error performance within a short code system (i.e., restores the interference averaging advantages of long code systems) while retaining the benefit of reduced MUD computational complexity associated with short codes.

Brief Description of the Drawings

FIG. 1 shows a prior art synchronous CDMA communications system in which K users simultaneously access a receiver via a single AWGN channel.

FIG. 2 shows a prior art decorrelating MUD for a synchronous CDMA communication system.

FIG. 3 shows a CDMA communication system utilizing short code hopping in accordance with the preferred embodiment of the present invention.

FIG. 4 shows a decorrelating MUD in accordance with the preferred embodiment of the present invention.

FIG. 5 is a flow chart illustrating operation of the CDMA communication system of FIG. 3 in accordance with the preferred embodiment of the present invention.

FIG. 6 is a block diagram of a remote unit in accordance with the preferred embodiment of the present invention.

FIG. 7 shows a Time Division, Multiple Access (TDMA) Communication system in accordance with the preferred embodiment of the present invention.

Detailed Description of the Drawings

To overcome the problems described above a method and apparatus is now described for hopping the short spreading code assigned to each user in a Direct-Sequence Spread-Spectrum (DS-SS) Code Division Multiple Access (CDMA) communications system. The sequence of short spreading codes employed by each user is determined by a pseudo-random hashing function. The set of short spreading codes available to each user is drawn from one or more (possibly disjoint) sets of short spreading codes made available to a cellular communication system. The sequence of short spreading codes employed by each user is ensured unique by assignment of a user-specific hashing function key. By hopping each user's short code, the bit error performance experienced by each user is averaged over the set of short codes through which the users are hopped.

Accordingly, the bit error performance experienced by each user is made the same – that is, the interference averaging property of long code spreading is restored – while the advantages of short codes in reducing the computational complexity of multi-user detectors may be exploited.

The present invention encompasses a method of code spreading in a Code Division Multiple Access (CDMA) communication system. The method comprises the steps of transmitting during a first time period via a first remote unit utilizing a first spreading code and transmitting during the first time period via a second remote unit utilizing a second spreading code. Next, during a second time period transmission takes place via the first remote unit utilizing a third spreading code and via the second remote unit utilizing a fourth spreading code.

The invention additionally encompasses a method of code spreading in a communication system. The method comprises the steps of choosing a first spreading code from a group of spreading codes and choosing a second spreading code from the group of spreading codes. Information is spread at a first remote unit, during a first time period, with the first spreading code and at a second remote unit, during the first time period, with the second spreading code. Next, a third and a fourth spreading code is chosen from the group of spreading codes and information is spread at the first remote unit, during a second time period, with the third spreading code and at the second remote unit, during the second time period, with the fourth spreading code.

The invention additionally encompasses an apparatus for spreading information in a code division multiple access communication system. The apparatus comprises a short code generator utilized for choosing a first short code from a set of short codes for use by a spreader during a first time period, and choosing a

second short code from the set of short codes for use by the spreader during a second time period.

The invention additionally encompasses an apparatus for receiving spread information in a code division multiple access communication system. The apparatus comprises a despreader for receiving spread information symbols transmitted by a plurality of remote units and outputting despread symbol information. The apparatus additionally comprises a symbol permutation function for assigning despread information symbols to users based on a knowledge of a time varying short code assignment to individual remote units within the commination system.

FIG. 3 shows a CDMA communication system utilizing short code hopping in accordance with the preferred embodiment of the present invention. As shown in FIG. 3, communication by multiple remote units 313-317 occurs simultaneously to base station 331 within the same frequency band. Therefore, a received signal at a base station comprises a multiplicity of frequency and time overlapping coded signals from individual remote units. Each of these signals is transmitted simultaneously at the same radio frequency (RF) and is distinguishable only by its specific spreading sequence. In other words, the signal 112 received at base-station 331 is a composite signal (shown summed at 110) of each transmitted signal plus thermal noise 111. An individual signal is distinguishable by base station 331 only after despreading.

In the preferred embodiment the permanent assignment of short codes is replaced by a short code generator 310 that produces a code hopping arrangement that hops the code assigned to each user at the channel encoded symbol rate. In other words, unlike the prior-art short code assignment, in the preferred embodiment of the present invention, an individual user's short code will be continuously updated (changed) at the symbol rate. Thus, the code s_k 306-308 assigned to user k during symbol i becomes a function $s_k(i)$ 306-308 of the symbol index. Accordingly, the bit error performance experienced by each user is averaged over the set of short codes through which the users are hopped.

In more detail, FIG. 3 shows the availability of a finite number Q of short codes forming a code pool Γ 305 that is shared between each of the K users present. User k is assigned short code $\mathbf{s}_k(i)$ 306-308 during symbol i in accordance with a number of mapping functions, including independent random assignment or cyclic code assignment. The preferred method, however, is to use a hashing function 304.

Hashing functions in accordance with the preferred embodiment of the present invention are described in "The Art of Computer Programming" by D. Knuth, and incorporated by reference herein. As described by Knuth, in the preferred embodiment, hashing function 304 specifies, for each symbol interval, a mapping from the set Γ 305 of available short codes to the set of users, where it is assumed that the number Q of codes is equal than or greater to the number K of users. The mapping is one-one within any symbol interval. In other words, any individual code is not assigned to more than one user. The mapping varies in pseudo-random fashion from symbol to symbol, with the sequence of codes $\mathbf{s}_k(i)$ 306-308 assigned to user k determined by the unique hashing key l_k 301-303 assigned to that user. (The period over at which the hashing function 304 is executed need not be the channel coded symbol interval. In an alternate embodiment of the present invention the hashing function 304 executes at a rate specified by the cellular system network.)

For many of the multi-user detectors described above, the computational complexity of the MUD is unaffected by the short code hopping procedure of FIG. 3. Continuing with the example of the decorrelating MUD discussed above, this can be shown – for the case where there are K available short codes and K users – by viewing the mapping envisaged by the hashing function as a permutation of the symbols $b_k(i)$ comprising the transmitted symbol vector $\mathbf{b}(i)$. That is, the hashing function may be defined as a matrix $\mathbf{M}(i)$ whose elements have value 0 or 1. Only one element in any row (or column) of $\mathbf{M}(i)$ is non-zero, and each row (or column) is unique. Defining the permuted symbol vector $\mathbf{d}(i)$ as

$$\mathbf{d}(i) = \mathbf{M}(i)\mathbf{b}(i)$$

the solution vector $\hat{\mathbf{d}}(i)$ available at the decorrelating MUD output is then

$$\begin{aligned}\hat{\mathbf{d}}(i) &= \mathbf{Lr}(i) = [\mathbf{S}^H\mathbf{S}]^{-1}\mathbf{S}^H[\sqrt{E_b}\mathbf{Sd}(i) + \mathbf{n}(i)] \\ &= \sqrt{E_b}\mathbf{d}(i) + [\mathbf{S}^H\mathbf{S}]^{-1}\mathbf{S}^H\mathbf{n}(i) \\ &= \sqrt{E_b}\mathbf{d}(i) + \mathbf{m}(i)\end{aligned}$$

which may be permuted to form $\hat{\mathbf{b}}(i)$ by simply applying the trivial inverse permutation operator $\mathbf{M}^{-1}(i) = \mathbf{M}^T(i)$ according to

$$\begin{aligned}\hat{\mathbf{b}}(i) &= \mathbf{M}^{-1}\hat{\mathbf{d}}(i) = \sqrt{E_b}\mathbf{M}^{-1}\mathbf{d}(i) + \mathbf{M}^{-1}\mathbf{m}(i) \\ &= \sqrt{E_b}\mathbf{b}(i) + \mathbf{m}'(i)\end{aligned}$$

FIG. 4 shows a decorrelating MUD in accordance with the preferred embodiment of the present invention. As shown, DSP 207 is followed by a simple symbol permutation function 401 that inverts the effect of hashing function 304. The inverse operator $[\mathbf{S}^H\mathbf{S}]^{-1}$ derived by DSP 207 need not therefore be updated at the code hopping rate, and the computational complexity of DSP 207 is preserved. In other words, DSP 207, acting as a despreader, receives spread information symbols transmitted by a plurality of remote units and despreads the spread information symbols, but makes no assignment of recovered symbols to individual users. Rather, the symbol permutation function 401 assigns recovered symbols to users based on a knowledge of a time varying short code assignment to individual remote units within the communication system.

In an alternate embodiment, the symbol permutation function 401 is redefined to be a sequence permutation function where the symbol permutation matrix $\mathbf{M}(i)$ is preserved for several symbols consistent with the code-hashing rate.

In the preferred embodiment of the present invention the system the pool Γ 305 of Q available short codes is derived from a set of P short codes available in the same frequency band across the entire cellular communication system, where $P \geq Q$. The code set Γ_n of short codes assigned to the n-th cell are disjoint with the set Γ_m of codes assigned to the m-th cell, for any n and m, although this would not be strictly necessary. Additionally, the hashing key l_k 301-303 may be assigned to a cellular mobile station during manufacture, upon origination of a call attempt, and/or following a handoff between system cells.

FIG. 5 is a flow chart illustrating operation of a CDMA communication system of FIG. 3 in accordance with the preferred embodiment of the present invention. The logic flow begins at step 501 where a first remote unit (e.g., remote unit 313) is transmitting to base station 331 during a first time period (symbol period, typically less than 1 millisecond) utilizing a first short spreading code (e.g., short code 306, 307, or 308). Additionally, at step 501, a second remote unit is transmitting to base station 331 during the first symbol period utilizing a second short spreading code. As discussed above, all remote units within the communication communicate simultaneously within the same frequency band. Therefore, a received signal at base station 331 comprises a multiplicity of frequency and time overlapping coded signals from individual remote units.

At step 505, the first and second remote units determine if the first symbol (time) period has passed, and if not the logic flow returns to step 501, otherwise the logic flow continues to step 510. At step 510 the first remote unit transmits to base station 331 during a second symbol period utilizing a third short spreading code. Additionally, at step 510 the second remote unit transmits to base station 331 during the second symbol period utilizing a fourth short spreading code. As discussed above, in the preferred embodiment, hashing function 304 specifies, for each symbol interval, a mapping from the set Γ 305 of available short codes to the set of users, where it is assumed that the number Q of codes is equal than or greater to the number K of users. The mapping is one-one within any symbol interval. In other words, any individual code is not assigned to more than one

user. The mapping varies in pseudo-random fashion from symbol to symbol, with the sequence of codes $s_k(i)$ 306-308 assigned to user k determined by the unique hashing key l_k 301-303 assigned to that user. Therefore, with reference to FIG. 5, the third short spreading code utilized by the first remote unit during the second symbol period, may potentially be the second short spreading code utilized by the second remote unit during the first time period. Likewise, the fourth short spreading code utilized by the second remote unit during the second symbol period may potentially be the first short spreading code utilized by the first remote unit during the first symbol period.

FIG. 6 is a block diagram of remote units 313-317 in accordance with the preferred embodiment of the present invention. Remote unit 313 includes convolutional encoder 612, interleaver 617, orthogonal encoder 620, modulator 652, upconverter 656, and short code generator 310.

During operation, signal 610 (traffic channel data bits), is output by a voice encoder (vocoder) and is received by convolutional encoder 612 at a particular transmission rate (e.g., 9.6 kbit/second). Input traffic channel data bits 610 typically include voice converted to data by a vocoder, pure data, or a combination of the two types of data, and is output at a particular data rate (i.e., full rate, 1/2 rate, 1/4 rate, 1/8 rate . . . etc.). Convolutional encoder 612 determines the transmission rate and encodes input data bits 610 into data symbols at a fixed encoding rate with an encoding algorithm which facilitates subsequent maximum likelihood decoding of the data symbols into data bits (e.g. convolutional or block coding algorithms). For example, convolutional encoder 612 encodes input data bits 610 (received at a rate of 9.6 kbit/second) at a fixed encoding rate of one data bit to three data symbols (i.e., rate 1/3) such that convolutional encoder 612 outputs data symbols 614 at a 28.8 ksymbol/second rate.

Data symbols 614 are then input into interleaver 617. Interleaver 617 interleaves the data symbols 614 at the symbol level. In interleaver 617, data symbols 614 are individually input into locations within a matrix so that the matrix is filled in a column by column manner. Data symbols 614 are individually output from locations within the matrix so that the matrix is emptied

in a row by row manner. Typically, the matrix is a square matrix having a number of rows equal to the number of columns; however, other matrix forms can be chosen to increase the output interleaving distance between the consecutively input non-interleaved data symbols. Interleaved data symbols 618 are output by interleaver 617 at the same data symbol rate that they were input (e.g., 28.8 ksymbol/second). The predetermined size of the block of data symbols defined by the matrix is derived from the maximum number of data symbols which can be transmitted at a predetermined symbol rate within a predetermined length transmission block. For example, in a full rate transmission if the predetermined length of the transmission block is 20 milliseconds, then the predetermined size of the block of data symbols is 9.6 ksymbol/second times 20 milliseconds times three which equals 576 data symbols which defines a 24 by 24 matrix.

Interleaved data symbols 618 are input to orthogonal encoder 620. For IS-95-type transmission orthogonal encoder 620 M-ary modulates the interleaved data symbols 618. For example, in 64-ary orthogonal encoding, each sequence of six interleaved data symbols 618 is replaced by a 64 symbol orthogonal code. These 64 orthogonal codes preferably correspond to Walsh codes from a 64 by 64 Hadamard matrix wherein a Walsh code is a single row or column of the matrix. The orthogonally encoded signal is output as signal 622.

Signal 622 is spread by a particular spreading code by spreaders 624. The spreading code (short code) is a specific sequence of symbols which is output at a fixed chip rate (e.g., 1.2288 Mchip/second). As discussed above, the sequence of short spreading codes employed by each user is determined by a pseudo-random hashing function with the set of short spreading codes available to each user drawn from one or more (possibly disjoint) sets of short spreading codes made available to a cellular communication system. The sequence of short spreading codes employed by each user is ensured unique by assignment of a user-specific hashing function key. The I-channel and Q-channel code spread sequences 626 are used to bi-phase modulate a quadrature pair of sinusoids by driving the power level controls of the pair of sinusoids. The sinusoids output signals are summed, bandpass filtered, translated to an RF frequency, amplified, filtered via

upconverter 656 and radiated by antenna 658 to complete transmission of channel data bits 610.

The descriptions of the invention, the specific details, and the drawings mentioned above, are not meant to limit the scope of the present invention. For example, the technique described above may be extended to the frequency division duplex (FDD) mode of the ETSI UMTS air interface described in Appendix A of ETSI Document 30.06, "UMTS Terrestrial Radio Access (UTRA) Concept Evaluation" modified to incorporate a hashing function in accordance with the preferred embodiment of the present invention as shown in FIG. 7. As shown, the hashing function – under control of the network-assigned hashing key l_k – hops the short code W_k through a set of Q available short codes defined *a-priori* by the network. Additionally, there are two physical layer sub-channels present in the particular example, namely a single Dedicated Physical Data Channel (DPDCH) 701 and a Dedicated Physical Control Channel (DPCCH) 702. In FIG. 7, the DPDCH 701 of user k offers a BPSK-modulated symbol sequence $b_k(i)$ 704 as the real part of a complex-valued symbol sequence, while the DPCCH 702 offers a constant symbol P 703 to the quadrature part. Note that the DPDCH 701 and DPCCH 702 are spread by orthogonal codes C_D 705 and C_C 706 respectively. After quadrature combination 707 both physical layer sub-channels are spread by a common length-256 scrambling code W_k which – in the existing approach – is assigned uniquely and continuously to user k. It is the intent of the inventors that various modifications can be made to the present invention without varying from the spirit and scope of the invention, and it is intended that all such modifications come within the scope of the following claims.

CLAIMS

1. A method of code spreading in a Code Division Multiple Access (CDMA) communication system, the method comprising the steps of:

transmitting during a first time period via a first remote unit utilizing a first spreading code;

transmitting during the first time period via a second remote unit utilizing a second spreading code;

transmitting during a second time period via the first remote unit utilizing a third spreading code; and

transmitting during the second time period via the second remote unit utilizing a fourth spreading code.

2. The method of claim 1 wherein the step of transmitting during the second time period via the first remote unit utilizing the third spreading code comprises the step of transmitting during the second time period via the first remote unit utilizing the second spreading code.

3. The method of claim 1 wherein the step of transmitting utilizing the first, second, third, and fourth spreading codes comprises the step of transmitting utilizing a first,.second, third, and fourth short code, respectively.

4. The method of claim 1 wherein thae step of transmitting during the first and second time period comprises the step of transmitting during a first and a second symbol period, respectively.

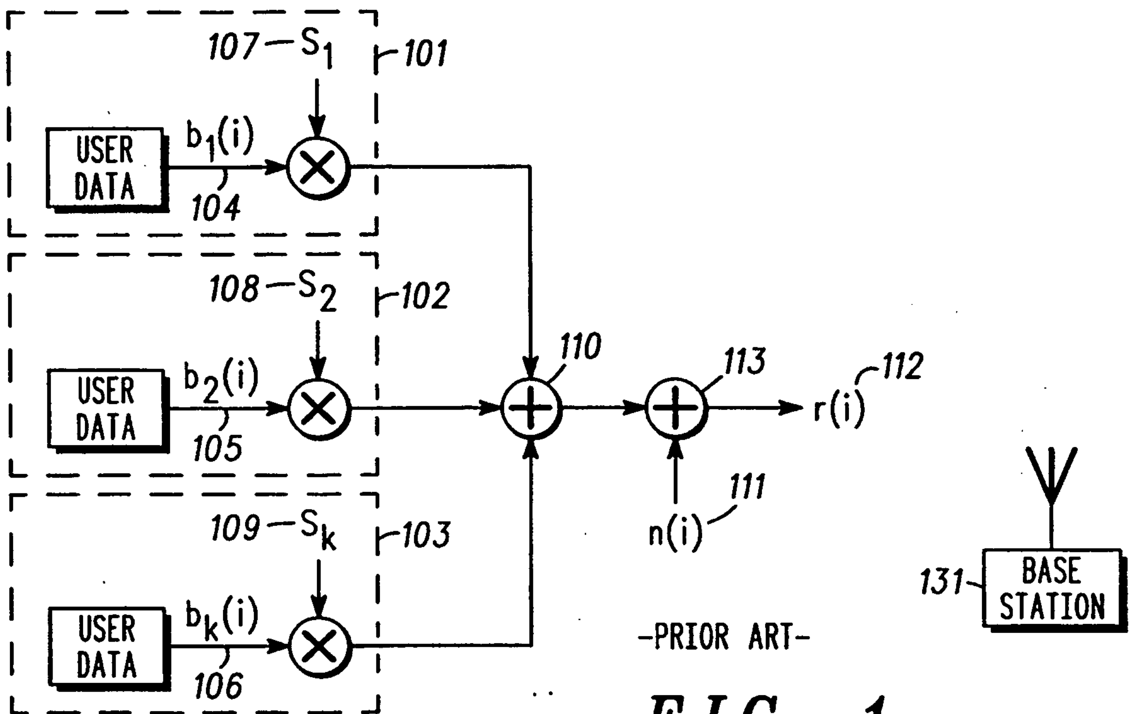
5. The method of claim 1 wherein the step of transmitting utilizing the first, second, third, and fourth spreading codes comprises the step of transmitting utilizing the first, second, third, and fourth spreading codes chosen from a group of spreading codes equal to, or greater than a number of users in the communication system.

6. An apparatus for spreading information in a code division multiple access communication system, the apparatus comprising a short code generator, the short code generator utilized for choosing a first short code from a set of short codes for use by a spreader during a first time period, and choosing a second short code from the set of short codes for use by the spreader during a second time period.

7. The apparatus of claim 6 wherein the short code generator chooses the first and the second short code by a unique hashing key.

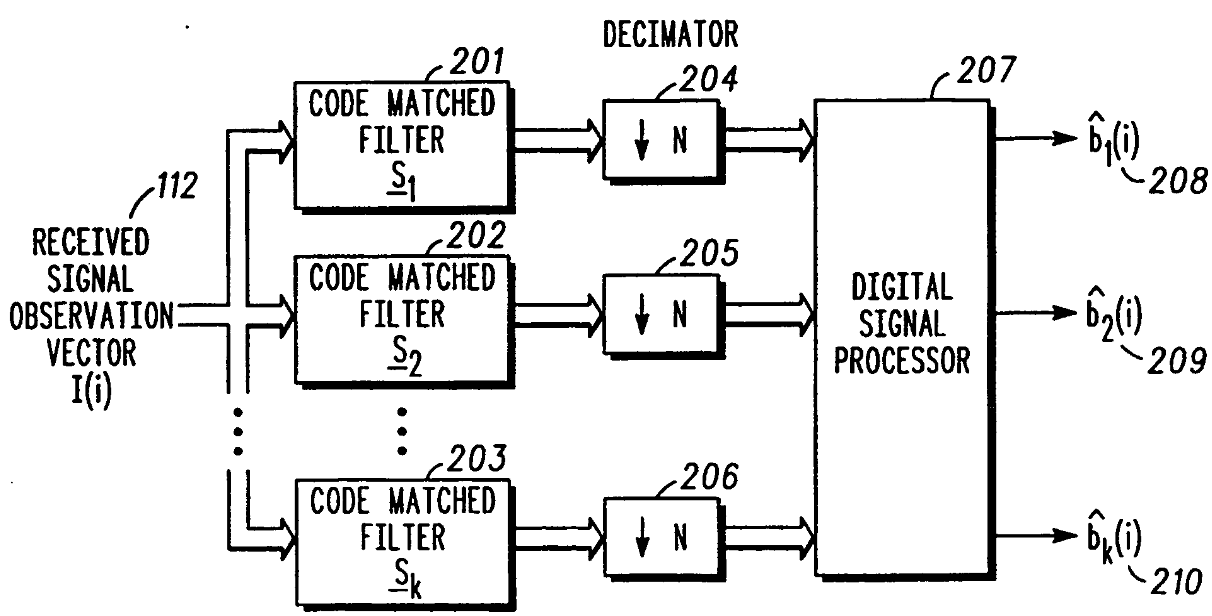
8. The apparatus of claim 6 wherein a number of short codes existing in the set of short codes is equal than or greater to a number of users in the communication system.

9. The apparatus of claim 6 wherein the first short code is not assigned to a second remote unit during the first time period.



-PRIOR ART-

FIG. 1



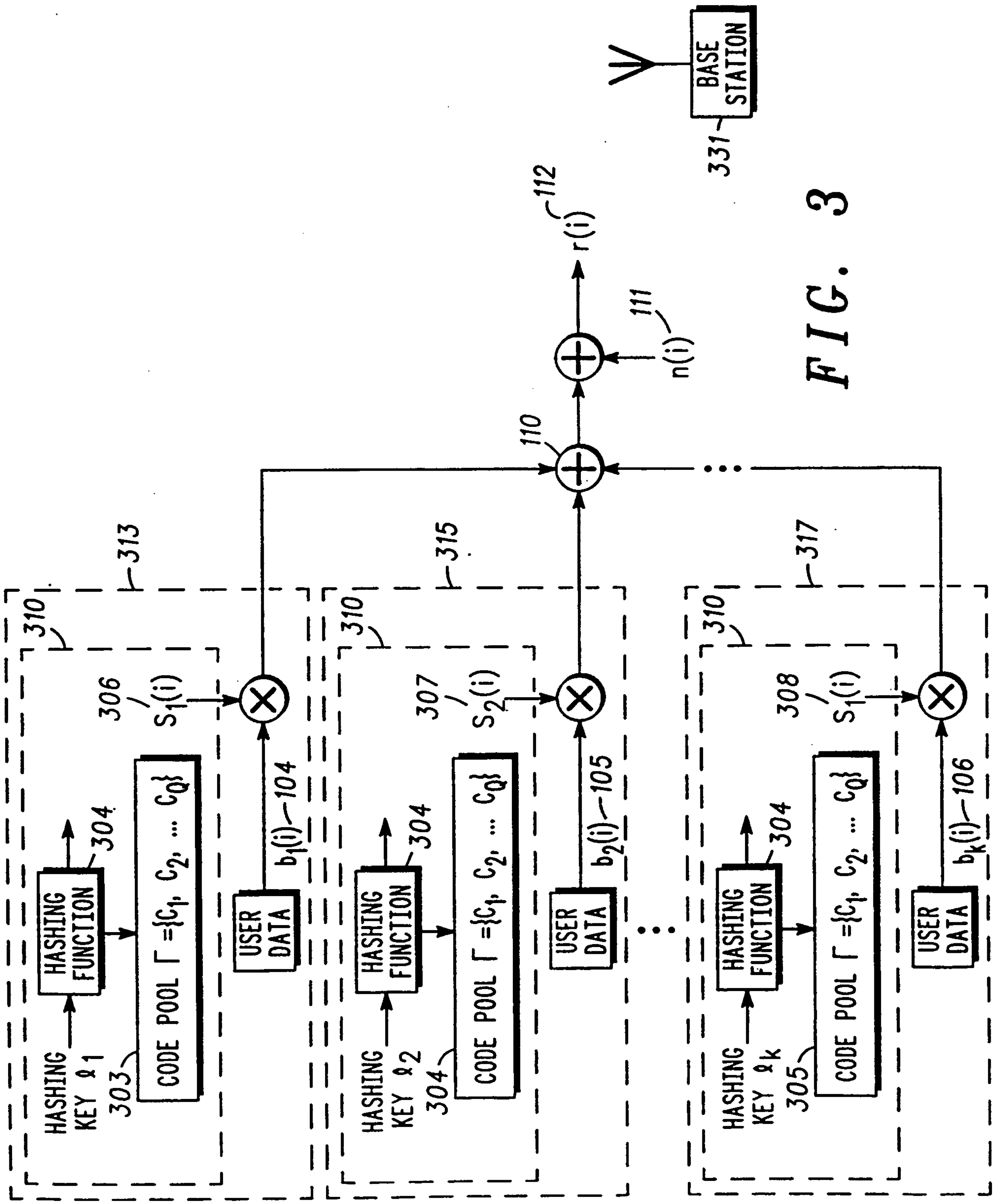

BASE STATION
331
112
r(i)
111
n(i)
110
313
315
317
310
306
$S_1(i)$
307
$S_2(i)$
308
$S_1(i)$
HASHING FUNCTION
304
HASHING KEY ℓ_1
HASHING KEY ℓ_2
HASHING KEY ℓ_k
CODE POOL $\Gamma = \{C_1, C_2, \ldots C_Q\}$
303
304
305
USER DATA
$b_1(i)$
104
$b_2(i)$
105
$b_k(i)$
106

FIG. 3

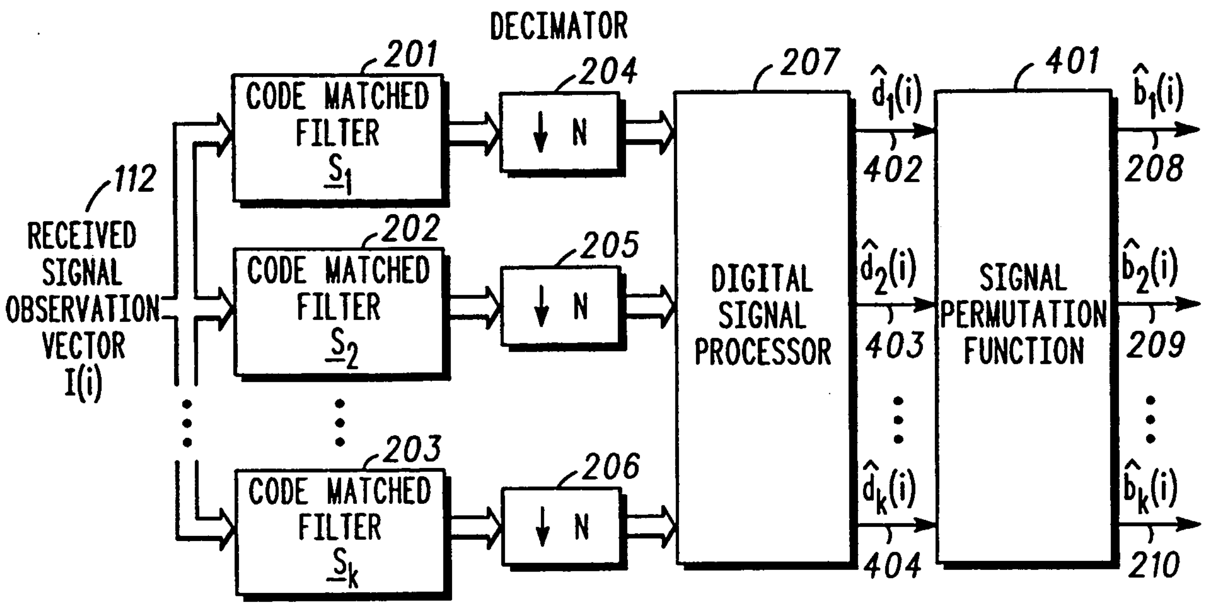
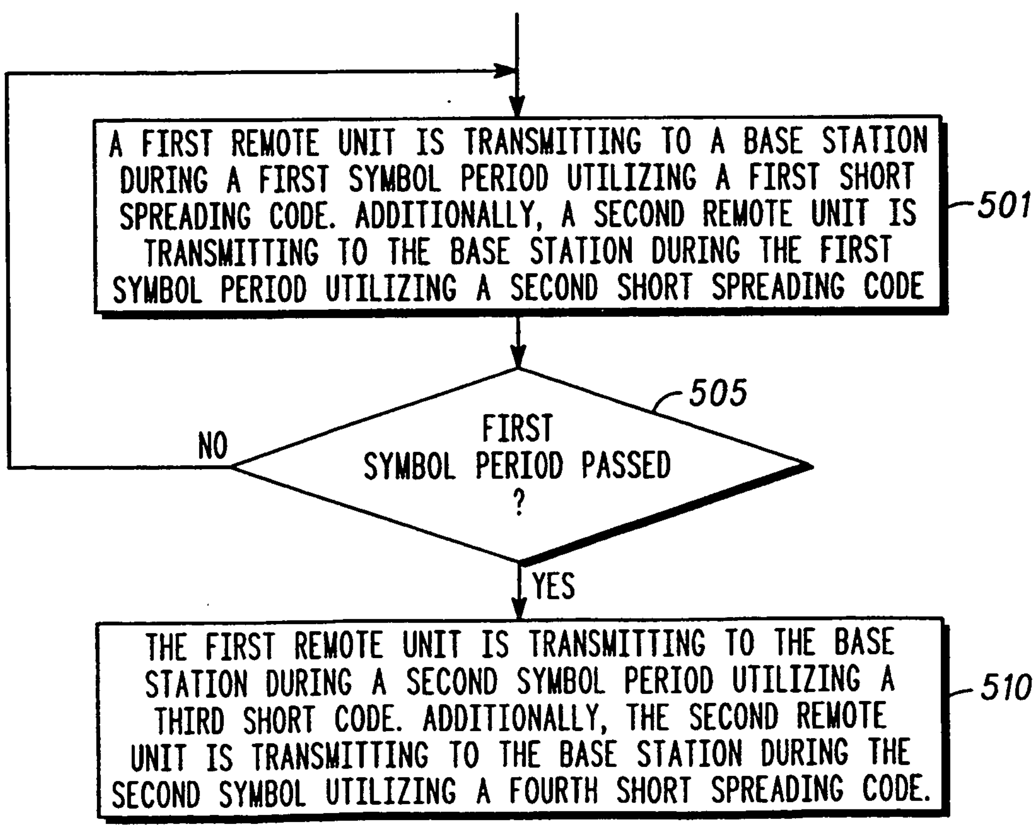

DECIMATOR
201
CODE MATCHED FILTER
$\underline{S}_1$
202
CODE MATCHED FILTER
$\underline{S}_2$
203
CODE MATCHED FILTER
$\underline{S}_k$
204
N
205
N
206
N
112
RECEIVED SIGNAL OBSERVATION VECTOR I(i)
207
DIGITAL SIGNAL PROCESSOR
$\hat{d}_1(i)$
402
$\hat{d}_2(i)$
403
$\hat{d}_k(i)$
404
401
SIGNAL PERMUTATION FUNCTION
$\hat{b}_1(i)$
208
$\hat{b}_2(i)$
209
$\hat{b}_k(i)$
210

FIG. 4


A FIRST REMOTE UNIT IS TRANSMITTING TO A BASE STATION DURING A FIRST SYMBOL PERIOD UTILIZING A FIRST SHORT SPREADING CODE. ADDITIONALLY, A SECOND REMOTE UNIT IS TRANSMITTING TO THE BASE STATION DURING THE FIRST SYMBOL PERIOD UTILIZING A SECOND SHORT SPREADING CODE
501
FIRST SYMBOL PERIOD PASSED ?
505
NO
YES
THE FIRST REMOTE UNIT IS TRANSMITTING TO THE BASE STATION DURING A SECOND SYMBOL PERIOD UTILIZING A THIRD SHORT CODE. ADDITIONALLY, THE SECOND REMOTE UNIT IS TRANSMITTING TO THE BASE STATION DURING THE SECOND SYMBOL UTILIZING A FOURTH SHORT SPREADING CODE.
510

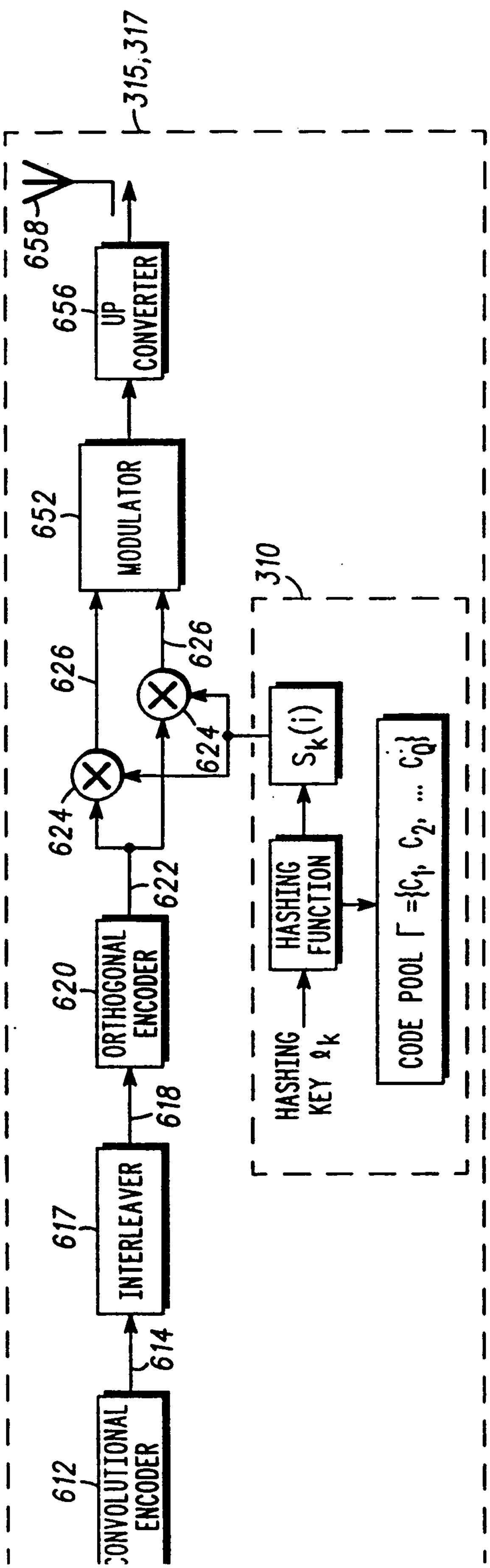

315,317
CONVOLUTIONAL ENCODER
612
614
INTERLEAVER
617
618
ORTHOGONAL ENCODER
620
622
624
626
MODULATOR
652
UP CONVERTER
656
658
310
HASHING KEY ℓ_k
HASHING FUNCTION
$S_k(i)$
CODE POOL $\Gamma = \{c_1, c_2, \ldots c_Q\}$

FIG. 6

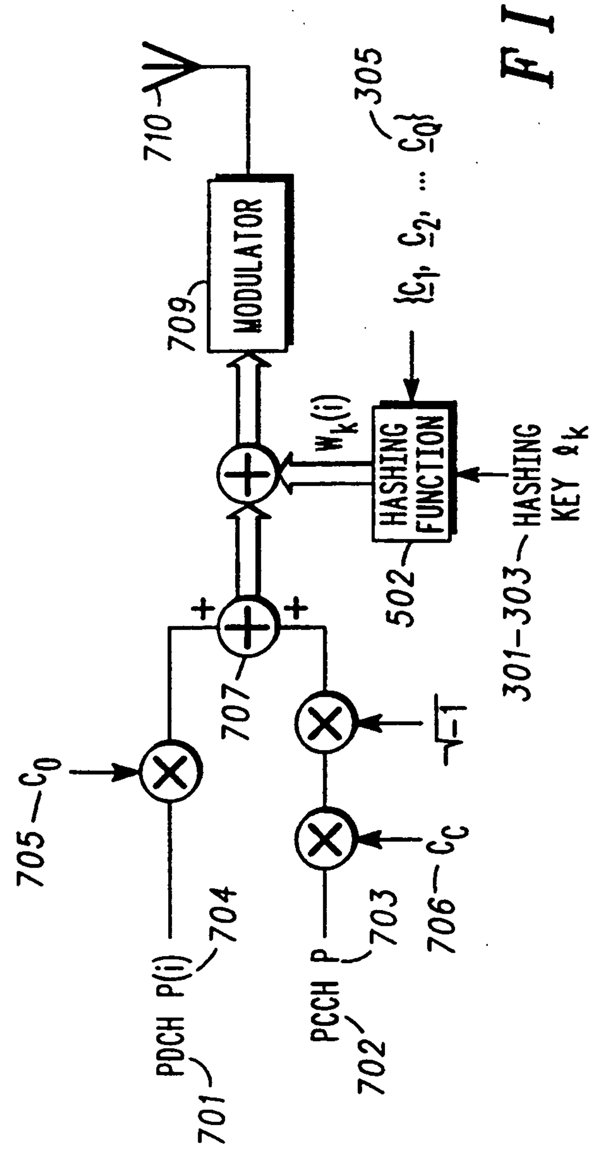

PDCH P(i)
701
704
PCCH P
702
703
705
c_0
706
c_c
$\sqrt{-1}$
707
+
+
$W_k(i)$
HASHING FUNCTION
502
301–303
HASHING KEY ℓ_k
$\{c_1, c_2, \ldots c_Q\}$
305
MODULATOR
709
710

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/04661

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 7/216, H04B 15/00
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 370/335, 336, 337, 341, 342, 329, 330, 343, 344, 345, 347, 441, 442; 375/200, 201, 202, 203, 204, 205, 206, 207

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,432,814 A (HASEGAWA) 11 July 1995, Col 2, lines 6-23; Fig 3.	1-9
Y	US 5,533,013 A (LEPPANEN) 02 July 1996, Col 7, lines 4-65.	1-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 MAY 1999	25 MAY 1999

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/04661

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

370/335, 336, 337, 341, 342, 329, 330, 343, 344, 345, 347, 441, 442; 375/200, 201, 202, 203, 204, 205, 206, 207